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16. ABSTRACT The paper discusses the development of a two-dimensional turbulent kinetic energy - dissipation rate (k-epsilon) turbulence model in the form of vorticity and stream functions. This turbulence model provides the distribution of turbulent kinematic viscosity, used to calculate the effective turbulent diffusion coefficient. These values were incorporated into the particle diffusion equation for determining the contaminant concentration profiles within an occupied space. The effects of locations of the supply air duct and the contaminant source on particle concentration distribution and ventilation effectiveness were investigated.

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CHARACTERISTICS OF TWO-DIMENSIONAL PARTICLE EDDY DIFFUSION IN OFFICE SPACE

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A two-dimensional turbulent kinetic energy-dissipation rate (k-ϵ) turbulence model in the form of vorticity and stream functions was developed. This turbulence model provides the distribution of turbulent kinematic viscosity, which is used to calculate the effective turbulent diffusion coefficient. These values were incorporated into the particle diffusion equation for determining the contaminant concentration profiles within an occupied space. The effects of locations of the supply air duct and the contaminant source on particle concentration distribution and ventilation effectiveness were investigated.

INTRODUCTION

Determination of contaminant concentration distribution within an occupied space is essential for evaluating indoor air quality and for designing ventilation systems. To predict or mathematically assess the quality of indoor air to which occupants may be exposed, the rates of generation, ventilation method, contaminant diffusion, airflow distribution, removal of contaminants, etc., must be evaluated. The objective of this research is to develop a model to evaluate the effectiveness of the ventilation in an indoor space.

Numerous models have been developed to calculate airflow distribution and concentration profiles (1-3), many of these being supplied by the clean room research community (4-6). However, these models do not adequately account for various parameters such as supply/return air duct location and source location. Especially, the contaminant concentration at occupants' respiratory levels (1.0 to 1.5 m from the floor) will be an important consideration for evaluating the indoor air quality and the ventilation effectiveness.

A two-dimensional k-ϵ turbulence model was used to predict airflow dynamics and the effective turbulence diffusion coefficient for a typical office space. The turbulence model was incorporated into the particle diffusion model to solve the particle concentration profiles. The qualitative effects of the placement of the supply air duct and the location of the source on the contaminant distribution are discussed.

COMPUTATIONAL AIRFLOW SIMULATION

Most airflows that actually occur within an indoor space will be turbulent flow. Because turbulent flow produces a complex, irregular, and time-dependent motion of vortices having various sizes, and because it is impossible to solve a microscopic turbulent flow, even with the most advanced supercomputers, it is sufficient to obtain a time-averaged flow field.

Among many existing turbulence models, we have developed a two-dimensional k-ϵ turbulence model in the form of a vorticity-stream function. The governing equations to describe Navier Stokes equations and Reynolds equations can be reduced to four instead of the five normally used. Hence, the computational time can be significantly reduced.

In order to calculate the contaminant concentration distribution, the turbulence model must be incorporated into the particle diffusion equation. All the dependent variables are nondimensionalized by the supply air duct dimension and inlet airflow velocity. These equations are expressed as a finite difference form and solved simultaneously with appropriate boundary conditions using a microcomputer. The detailed formulation and computational procedures for describing this model cannot be presented, due to space limitations, but will be published elsewhere in the future.

Figure 1 shows the computational domain and the locations of the supply air duct and source. The constant source at either location 1 or 2, and two different inlet duct placements were chosen for this simulation. The grid points used for this computation were 17x17.

RESULTS AND DISCUSSION

First, the supply duct was placed at the center of the ceiling and the exhaust duct was located at the bottom of the side wall. Figure 2(a) shows the airflow streamlines in the room. Two large recirculation zones were observed for both sides of the main airflow path. The strength of flow recirculation was slightly greater for the right-hand side. The strength of recirculation is an index of how strongly contaminants can be entrained and trapped in the recirculation zone. Once contaminants are trapped in such a recirculating zone, they rarely escape from this region unless strong external forces such as electrostatic force are present. Clearly, flow recirculation is not a favorable condition. Figure 2(b) shows the time-averaged velocity distributions. Note that the fluid velocity is nondimensionalized by the inflow velocity of 0.5 m/s. Combining velocity plots and flow streamlines allows detailed time-averaged flow information to be produced.

It is important to understand the distribution of contaminant diffusion because it is the measure of airflow mixing. The contaminant diffusion consists of the diffusion due to Brownian motion and the diffusion due to the turbulence kinetic energy. The turbulent kinematic viscosity, found by solving the turbulence model, can be used to calculate the normalized effective turbulent diffusion coefficient and its distribution (Figure 3). Note that the actual turbulent diffusion coefficients are 0.2 times the values shown in Figure 3. The highest diffusion takes place at the bottom of the main flow path. Because the effective turbulent diffusion coefficient represents air mixing, a higher contaminant mixing takes place at the region of higher diffusion. The next highest

diffusion appears in the vicinities of inflow and outflow and the main flow stream region. In general, the contaminant diffusion diminishes with increasing distance from the main airflow path.

Figure 4 shows the steady-state contaminant concentration distribution when the source is placed at the left side of the main airflow stream (location 1 in Figure 1). Note that the contaminant level shown in Figure 4 is a relative value. The contaminant concentration is significantly higher on the left-hand side of the main airflow stream but very few contaminants are present at the right-hand side of the main airflow stream. This implies that the main airflow stream behaves like an air curtain despite contaminant diffusion.

When the source is at the right-hand side of the room (location 2), the contaminant concentration distributions are as shown in Figure 5. Because the source is located in the main airflow stream, the average concentration is significantly lower (less than one-third), compared to that for Figure 4. Most of the contaminants are swept away by the main airflow, but some are diffused to the upper-right section of the room.

Figures 6(a) and 6(b) show the airflow streamlines and velocity vectors when the supply air duct is shifted to the left. The airflow distribution is completely modified and only one large recirculation is observed at the upper-right corner of the room.

Figure 7 shows the distribution of the effective turbulent diffusion coefficient with the supply air at the left. Although its distribution is significantly changed, the relative value remains about the same (see Figure 3). In other words, the effective turbulent diffusion coefficient is higher along the main airflow path and becomes lower at the stagnation region.

Figure 8 shows the contaminant concentration profile when the source is at the left side (location 1). The average concentration for this case is significantly smaller compared to the case where the supply duct is located at the center (see Figure 4) because the source is located in the main flow streamline.

Figure 9 shows the contaminant concentration distribution when the source is moved to the right side (location 2). As can be seen from the figure, most of the contaminants remain in the upper-right-hand corner, indicating poor ventilation. The average concentration becomes more than three times higher than in the case of Figure 8. It is clear that the ventilation effectiveness is largely affected by the source locations and the airflow distributions in a room for all cases. For future work, more quantitative information is required to incorporate parameters discussed in this paper, as well as other parameters such as diffuser design and room configuration, toward further understanding the effective ventilation of indoor space.

CONCLUSIONS

A two-dimensional k-ϵ turbulence model and a contaminant diffusion model were developed to determine the turbulence flow field, effective turbulent diffusion coefficient, and the contaminant distribution. More effective ventilation is achieved when the source is placed within the main flow stream. In general, ventilation effectiveness is improved by minimizing the air recirculation zone and the strength of the recirculation.

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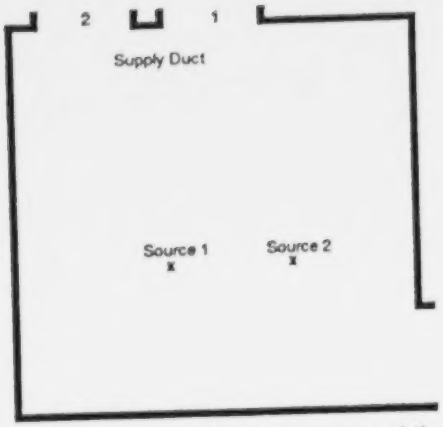

Figure 1. Computational domain and the locations of the supply air duct and source.

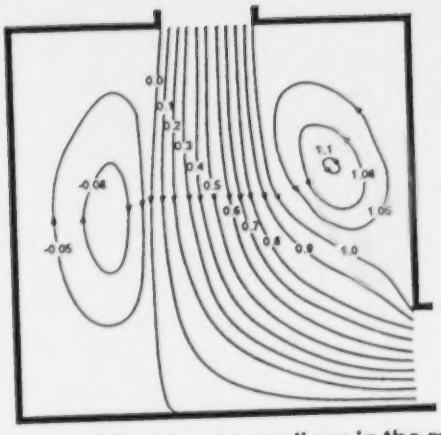

Figure 2. (a) Airflow streamlines in the room (inflow velocity of 0.5 m/s).

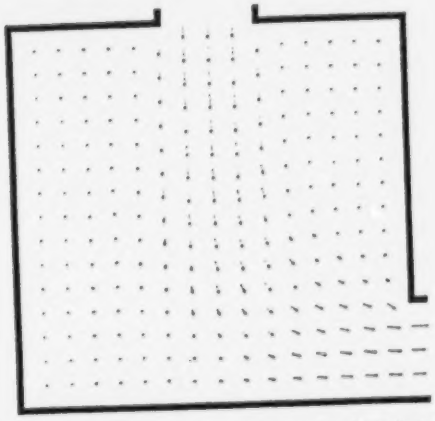

Figure 2b. Time-averaged velocity distributions in the room (inflow velocity of 0.5 m/s).

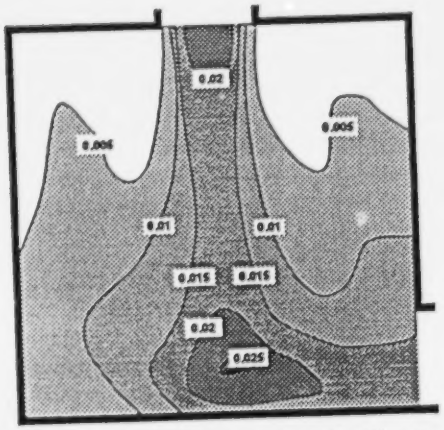

Figure 3. Distribution of the effective turbulent diffusion coefficient.

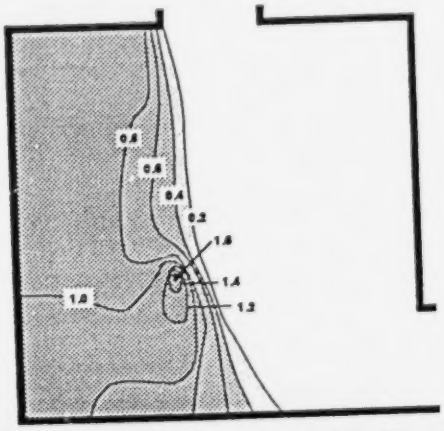

Figure 4. Steady-state contaminant concentration distribution when the source is placed at location 1.

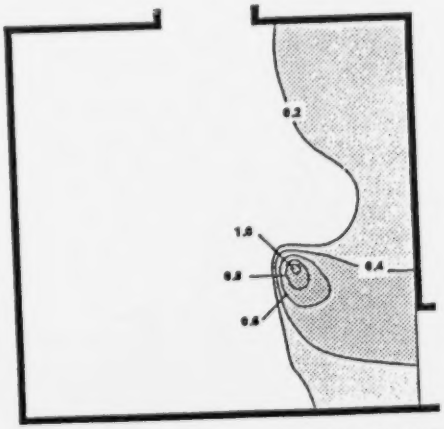

Figure 5. Steady-state contaminant concentration distribution when the source is placed at location 2.

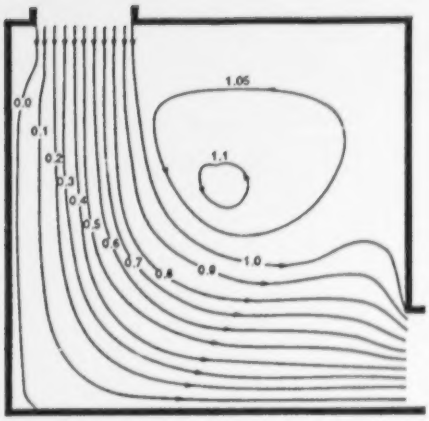

Figure 6a. Airflow streamlines when the supply air duct is the left side.

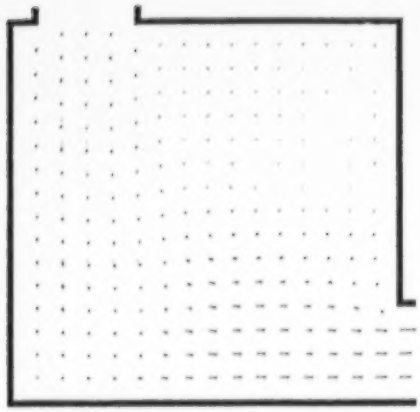

Figure 6b. Velocity vectors when the supply air duct is the left side.

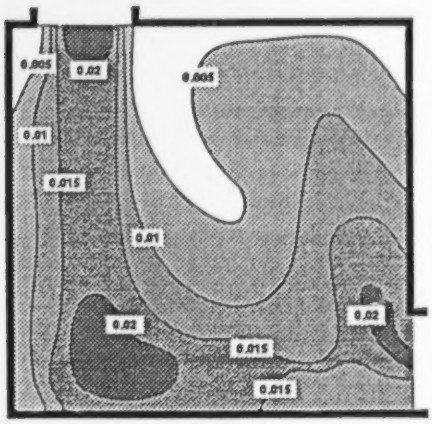

Figure 7. Distribution of the effective turbulent diffusion coefficient when the supply air duct is the left side.

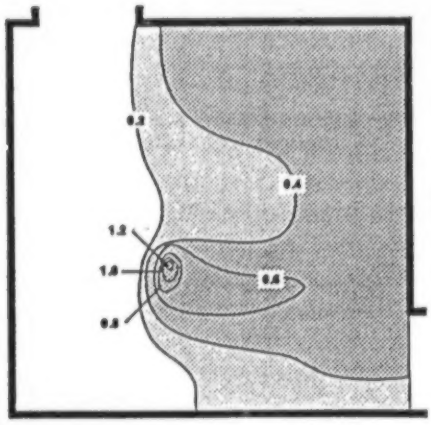

Figure 8. Contaminant concentration profile when the source is placed at location 1.

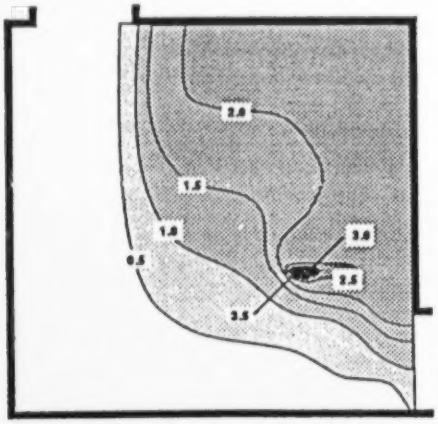

Figure 9. Contaminant concentration distribution when the source is placed at location 2.